Impact of Print Parameters and CSP Pitch and I/O on Paste Quality and Volume

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ABSTRACT

A JPL-led CSP Consortium of enterprises, composed of government agencies and private companies, recently joined together to pool in-kind resources for developing the quality and reliability of chip scale packages (CSPs) for a variety of projects. The Consortium's experience of the build of more than 150 test vehicle assemblies, single- and double-sided multilayer PWBs, and environmental test results is now published as a chip scale package guidelines document and is being distributed by Interconnection Technology Research Institute (ITRI).

Assembly of the second test vehicle with 15 packages is currently underway. As part of the assembly, an in depth study on solder paste print quality for mixed CSP and BGA packages was performed at two facilities, Celestica and Storage Technology. A series of experiments was performed to establish solder paste deposition with screen printing process variables. A 3D laser measuring system in conjunction with reference copper traces was used to automatically measure solder paste volume. The quality of print was established by visual inspection. This paper presents the effects of screen printing parameters including stencil thickness, aspect ratio, squeegee length, squeegee materials, and pressurized print head on solder paste volume for packages with pitches from 0.5 mm to 1.27 mm and I/Os from 48 to 784.

INTRODUCTION

In recent years, chip scale packages (CSPs) have emerged as the packaging technology of choice, fulfilling the electronic industry's continual need for smaller, faster and lighter products. This technology has found many applications in digital camcorders, flash memory cards, mobile phones, and telecommunications.

To investigate the many issues of implementing CSP technology and verifying its reliability, a Consortium led by the Jet Propulsion Laboratory (JPL) was formed to design and build a test vehicle with different types of CSPs [1,2].

Solder joint reliability is affected by many variables including the screen printing process especially for assemblies with mixed package technology. Two independent Consortium members assembled a large number of test vehicle number 2 (TV-2) and investigated the effects of manufacturing variables on solder paste release. Members that assembled test vehicles were:

a) Celestica, with extensive experience in ball grid array (BGA) and flip chip attachment process development and a goal of integrating CSPs into main stream SMT assembly[3]. Celestica's Customer Oriented Rapid Engineering Lab (CORE Lab, Facility A) completed the assembly of forty TV-2s in a high volume assembly production environment. Key screen printing process metrics including print quality and solder paste volumes for various CSPs and BGAs were established prior to the test vehicle build to understand key process variables, to verify previous results and for correlation to solder joint reliability.
b) Storage Technology, (Facility B) well-known for implementation of advanced microelectronic packaging for high reliability information storage and retrieval applications. Twelve TV-2s were built at Storage Technology's quick turn proto facility. Solder paste volumes were measured and compared to Facility A's measurements.

Solder paste deposition quality, i.e., solder paste consistency and volume, is critical to solder joint reliability. It has been shown that 40% of the soldering defects in SMT assembly are associated with the screen printing process[4]. This process is even more critical for CSPs with higher I/O and/or smaller physical features including pitch and solder bump.

A series of experiments was performed to correlate solder paste deposition with printing process variables for packages with various pitches and sizes. Previously, preliminary data on the effects of area aspect ratio of the stencil on the amount of solder paste released was presented[5]. This paper will present additional information gathered during the assembly of the JPL Consortium test vehicle (TV-2) covering many aspects of print quality and its correlation with manufacturing variables for a mixed package assembly. Other members of this Consortium have presented the reliability aspects in a paper[2], which is included in these proceedings.

TEST VEHICLE

The printed wiring board (PWB) had an OSP surface finish and a pad size variation from 0.25 mm to 0.66 mm and a pitch variation from 0.5 mm to 1.27 mm. An assembled test vehicle (TV-2) is shown in Figure 1. The section of PWB shown in Figure 2 includes pitches of 0.5, 0.8, 1.0, and 1.27 mm. Note the calibration traces designed close to the pads. These traces are reference surfaces for the automatic, 3D laser solder paste volume measurement system, which are required when pads are covered with paste.

Figure 1 - Assembled CSP and BGA TV-2

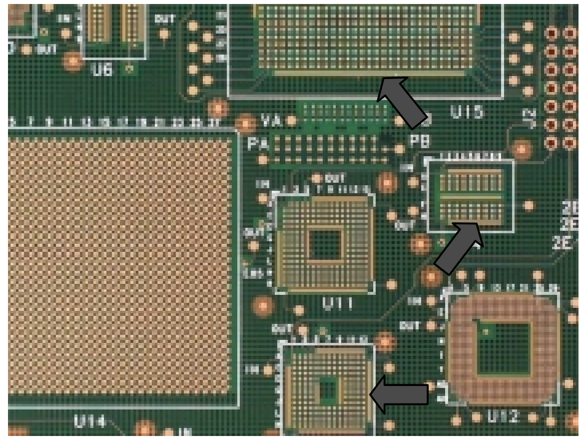

Figure 2 – Section of CSP and BGA TV-2

Experimental Runs and Test Vehicle Build

Experiments were performed prior to the build (herein, Runs) and during test vehicle build (herein, Builds) and had some differences. Table 1 lists process parameters for the four experimental Runs and Table 2 lists variables for the four Build assembly.

Table 1: Variables for screening printing of TV-2 for the Run experiment

Experimental Run	**Run 1**	**Run 2**	**Run 3**	**Run 4**
Equipment	Printer A	Printer A	Printer A	Printer B
Squeegee Angle	45	60	N/A Pressurized Head	60
Squeegee Blade Overhang	5 mm	15 mm	N/A Pressurized Head	22 mm
Print speed	Standard	Standard	Standard	Standard
Pressure	Standard	Standard	Standard	Standard

Table 2 Variables for screening printing of TV-2 for the Build experiment

Assembly Build	**Build 1**	**Build 2**	**Build 3**	**Build 4**
Equipment	Printer B	Printer B	Printer B	Printer B
Squeegee Angle	60	60	60	60
Squeegee Blade Overhang	22 mm	22 mm	22 mm	22 mm
Print speed	Standard	Standard	Standard	Standard
Pressure	Standard	Standard	Standard	Standard
# of PWBs	12	13	5	5
Stencil used	6 mil Laser cut	5.65 Efab Stencil	5.65 Efab Stencil	5 mil Laser cut

Run —For the Run investigation, two printers with fine-pitch print capabilities were used. Squeegee angles and overhang lengths were varied. The variables reflected generic screen printing processes for a manufacturing line. A pressurized printer head was used to compare against the squeegees. Only six package patterns on PWB, out of fifteen, were included in the Run experimental analysis.

Build —In the Build study, only one screen printer was used due to availability at the time of test vehicle build. The three different stencils used during the Build were:

- 150 µm (0.006 inch) thick laser-cut and fabricated out of stainless steel. This stencil was also used in the Run experiment
- 125 µm (0.005 inch) thick laser-cut and fabricated out of stainless steel
- 141 µm (0.00565 inch) thick electro-formed and fabricated out of nickel

Each stencil design incorporated square apertures with rounded corners. The electro-formed stencil incorporated the same aperture design as the 6 mil laser cut stainless-steel stencil. Thirteen out of fifteen PWB package patterns were characterized in the Build experiments.

Paste Print and Volume Measurement

The study included a no-clean paste, type III (-325+500) mesh, with a metal content of 90.25% and a viscosity of 900-1000 Kcps at room temperature (22 °C). Each PWB was visually inspected after screen printing for gross defects such as bridging or insufficient paste. Solder pastes were screened on the acceptable PWBs using normal manufacturing parameter setup. Registration of solder paste was ensured through normal screen printing protocols using sample PWBs and optical microscopy. Once the registration of the print met manufacturing standards, the PWBs were screen-printed. After each screen-print the underside of the stencil was wiped automatically or manually with a lint free cloth.

After screen print completion, solder paste volumes were measured by an automated 3-D vision inspection machine. The precision and confidence level of the data was assured by using multiple measurement. This process was carried out for the four different setups during the Run experiment and Build of test vehicle.

TEST RESULTS PERFORMED AT FACILITY A

The solder paste volume released by the screen printing process changes as the pad size decreases. In order to predict solder paste volume two parameters were considered.

- Release rate (percentage ratio of measured paste volume to a calculated theoretical volume)
- Aspect ratio (ratio of wall area to aperture area)

The relationship between the two parameters for the Runs and Builds were characterized.

Consistency or variability of the screen printing process, (i.e. variation for different sites of a package pattern in a PWB and different PWBs) was also determined using an analysis of variance (ANOVA) statistical approach. The process variation was calculated for each site. The variation values were then normalized with respect to the theoretical volume for each individual case based on a six sigma process. Details on the test results are discussed below.

Correlation of Paste Volume with Aspect Ratio

Figure 3 shows the relationship between release rate and aspect ratio for the Run experiment. The relationship between the release rate and the aspect ratio was assumed to be linear even though there appears to be non-linear regions at the two extremes. A similar relationship was found for the Build experiment as shown in Figure 4. The data for Builds 2 and 3 were combined since the same stencil was used in both cases. In general, as the aspect ratio increases the release rate also increases. The rate of increase depends on the Run or Build conditions. For example, the Run 4 release rate was more sensitive to the aspect ratio than the other Runs. The thicker stencil used in Build 1 showed less sensitivity to aspect ratio compared to other Builds with thinner stencils.

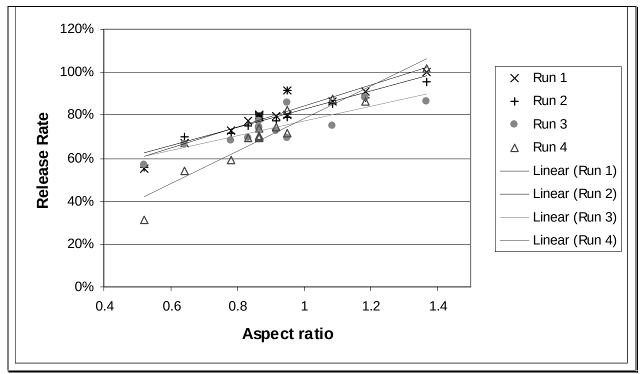

Figure 3 - Process characterization for Runs 1 to 4

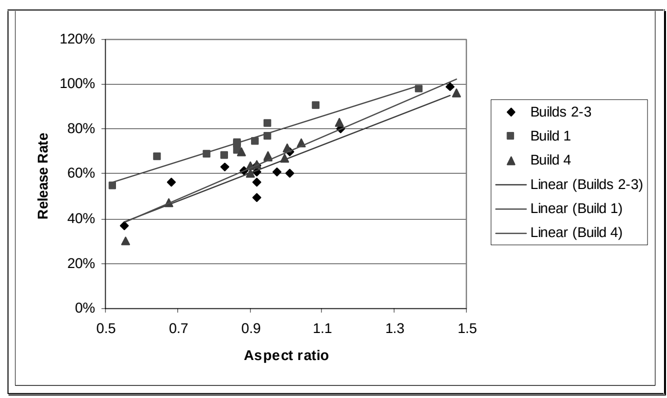

Figure 4 - Process characterization for Builds 1 to 4

Also, note that Run 1 and Build 4 have the same process conditions (including the same stencil thickness), except for the time of the experiment. Figure 5 shows the release rates for Run 4 and Build 1. Although both experiments show linear correlation, the release rate for the Build was less sensitive to aspect ratio than the Run experiment. At the lowest aspect ratio of 0.5 the release rate was about 20% higher for the Build than the Run.

Effect of Stencil Type on Release Rate

The stencil type has a direct impact on the release rates. For example, the release rates for the electro-formed stencils were more scattered (Builds 2 and 3) than laser cut version

(Build 1 and 4) as shown in Figure 4. This scatter can be attributed to the nature of the electro-formed stencil. The nominal thickness for this stencil was 5.65 mil +/- 0.5mils. The thickness was based on the inside walls of the aperture.

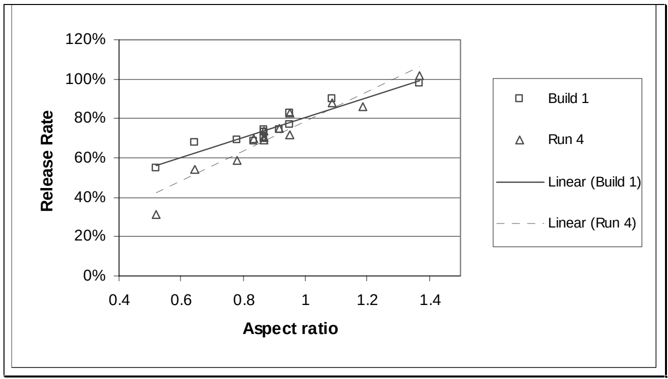

Figure 5 - Comparison between Run 4 and Build 1

Contrary to stainless steel stencils (+/- 0.4 mils), which are made of sheet metal an electro-formed stencil is grown on a mandrel from a solution. The solution contains nickel ions, which are discharged by an electric current and deposited on the mandrel containing a negative pattern of the stencil design. The density of the apertures of a site on the mandrel determines the growth rate of the nickel. Therefore, the areas of the stencil with higher aperture density may have a greater deposition rate than other areas and will result in a greater thickness of nickel at that site.

The variation in the thickness of an electro-formed stencil greatly affects the actual aspect ratio of the stencil compared with the original stencil design. As a result the true aspect ratio of the stencil should be determined by direct measurements of the stencil thickness and aperture dimensions. This implies that the relationship between the release rate and aspect ratio should be more carefully investigated to determine the true trend for the electro-formed stencil. The aspect ratio used in Figure 4 was the theoretical value based on stencil design. A different aspect ratio would be calculated for measured apertures compared to the theoretical aspect ratios. Consequently, the relationship between release rate and aspect ratio may have resulted in a true trend than what was observed initially.

The theoretical aspect ratio was also used for the laser cut stencils instead of the true or measured aspect ratio. But in this case, since the thickness of sheet metal is a more controlled process, the aspect ratios of these stencils were taken as a good approximation to the true value. As a precaution, measuring the actual stencil aperture dimensions of the laser cut stencils would be an important exercise.

Consistency of the Screen Printing Process for the Runs and Builds

The variations in processes were compared for different PWBs and sites on a PWB, using a two-factor ANOVA with replicates. For example, the size of the pads and therefore stencil openings will affect solder paste release. Clogging of aperture openings was observed more often for CSPs with 0.5 mm pitch than for packages with larger pitches. Figure 6 includes release rates as well as process variation as a function of aspect ratio for Run 1. As expected, the process inconsistency decreases as aspect ratio increases, from 20% for 0.5 ratio to 5% for 1.2 ratio. A similar trend was observed for experimental Runs 2 and 3. However, the variation for Run 4 was different and showed a parabolic relationship as shown in Figure 7. Variation is minimized (about 10 %) at about a 0.9 aspect ratio with the extreme values of about 40% and 30% at 0.5 and 1.35 aspect ratios, respectively.

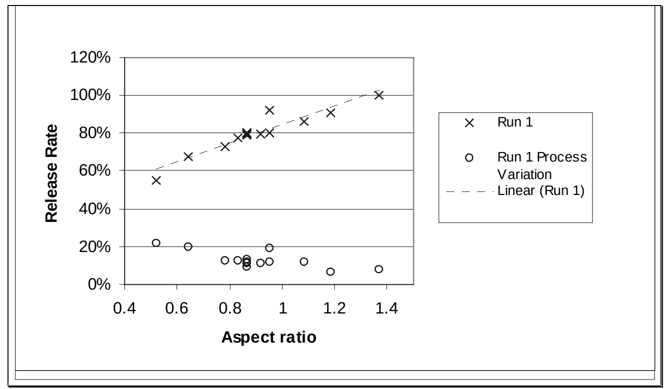

Figure 6 - Process variation for the Run 1

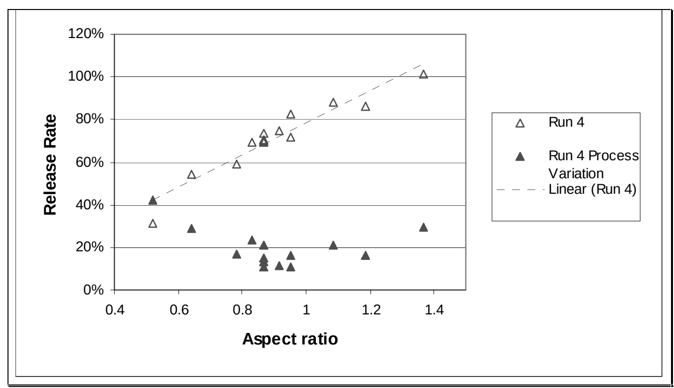

Figure 7 - Process variation for the Run 4

Verification of these results was an important step in determining the cause of this discrepancy. The process variation for Build 1 is shown in Figure 8. A similar trend was also observed for Run 4 as shown in Figure 9. The process variation value at 0.5 aspect ratio is high and is about 40%. It reduces to 15% at 0.85, and then increases to 33% at higher ratio of 0.9.

The cause for this non-linear trend in process variation value with aspect ratio is not well understood and is the focus of a future study. In addition, the Builds had higher process variation than the Runs in the range of 0.6 to 1 aspect ratios. The cause for this difference was not determined at this time. Possible causes include the use of different screen printing machines, solder paste from different lots and differences in operator skill.

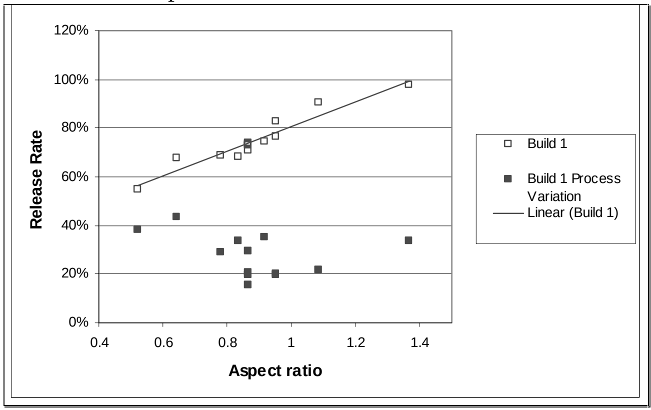

Figure 8 - Process variation for assembly build 1

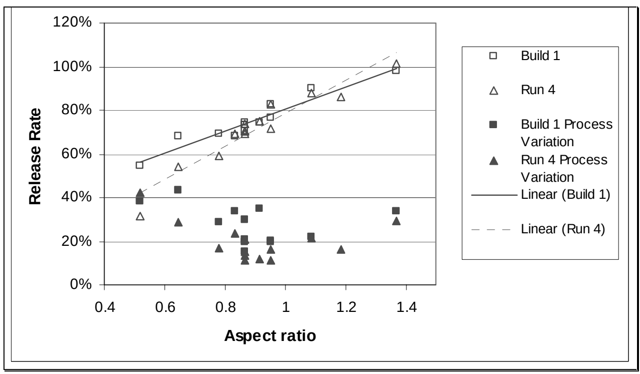

Figure 9 - Comparison of Experimental Run 4 and Build 1

Consistency of Screen Printing Process for Different PWBs and Pads

One of the useful advantages of an ANOVA is that the contribution of the general process variation can be narrowed to a more specific parameter. The PWB to PWB variation of the process as a function of aspect ratio is shown in Figure 10 for Run 4 and Build 1. The pad to pad variation for a site as a function of aspect ratio is shown in Figure 11 for Run 4 and Build 1.

Comparison of the two figures shows that the contribution of pad to pad variation is more significant than that of PWB to PWB variation. In addition, the PWB to PWB variation for Run 4 shows a similar decreasing trend to the variation observed in Run 1. This implies that although the process was consistent from PWB to PWB in Run 4 and Build 1, there was more variation from pad to pad on a site within a PWB. This also implies that the process was not optimized. The contributing factors could have been inconsistencies in the stencil apertures, position of the apertures of a site with respect to the PWB, direction of the roll of the paste during screen printing as well as other variables attributed to the equipment setup and operation.

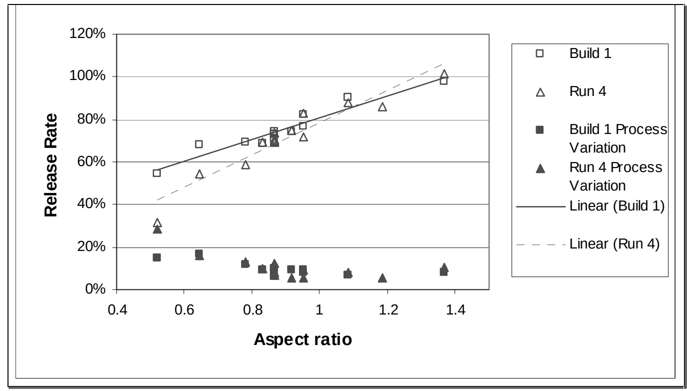

Figure 10 - Comparison of Run 4 and Build 1 for PWB to PWB variation

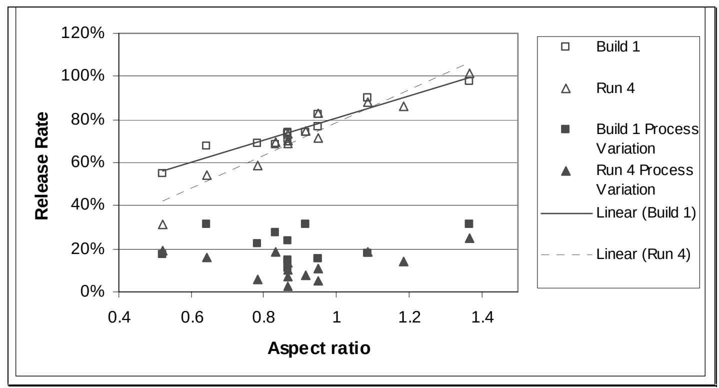

Figure 11 - Comparison of Run 4 and Build 1 for pad to pad variation

TEST RESULTS PERFORMED AT FACILITY B

Solder paste volume was also measured at Facility B during the assembly of twelve TV-2 test vehicles. Table 3 summarizes the measured paste volumes versus theoretical values. The shaded rows with package identifications (U8, U9, U11, U14, and U15) are suspect data and therefore were not considered in the plots of figure 11. For the theoretical volume calculation, the stencil apertures were all measured and actual measurements instead of design data was used.

DISCUSSION

The integration of CSPs into the current manufacturing process using standard SMT practices may require processes similar to those used for fine pitch packages that would maximizes CSP reliability. The effect of solder paste volume on the reliability of CSPs is yet to be determined, but it is assumed to be dependent on the amount of paste deposition during the manufacturing processes. An increase in solder paste to a certain level, should improve solder joint reliability, even though such a relationship is not yet established. To achieve higher manufacturing yield as well as improved reliability, key screen printing process parameters and control of paste deposition consistency needs to be understood. In-depth characterization provided here was aimed at understanding the key parameters that are required to be controlled for screen printing optimization as well defining relationship between solder paste volume and reliability.

Table 3 Percent Release Rate and Aspect Ratio for Various Packages (Facility B)

Location	Average Measured Volume	Theoretical Volume	Percent Release	Aspect Ratio
U1	1204	1574	76	0.95
U10	232	373	62	0.77
U11	1232	1402	88	0.92
U12	333	460	72	0.62
U13	1218	1436	85	0.91
U14	3103	3269	95	0.91
U15	1965	1900	103	0.83
U2	1374	1692	81	0.87
U3	4741	5267	90	0.61
U4	1460	1812	81	0.76
U6	1299	1617	80	0.83
U7	1693	1881	90	0.85
U8	1550	1511	103	0.90
U9	1479	1822	81	0.82

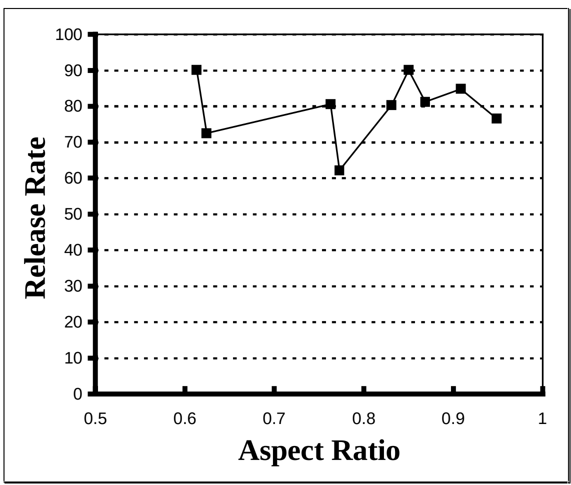

Figure 12 Release rate variation with aspect ratio from data generated at Facility B

CONCLUSIONS

Facility A

The in-depth investigation carried out at Facility A indicates that:

- Solder paste deposition quality (volume and consistency) is related to the aspect ratio of the stencil, the equipment, and screen printing parameters.
- For CSPs to be integrated into the main-stream assembly processes, screen printing results should approach that of BGAs with the highest release rate and high levels of process consistency.

- The screen printing process and paste deposition must be optimized and controlled for a mixed technology/CSP assembly to assure the reliability of the assembly.

Facility B

- The limited data gathered at Facility B did not show the strong correlation or trend between release rate and aspect ratio that was determined at Facility A. Further investigation with much larger sample sizes is required to better understand the reasons for such differences.

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